Measuring beam polarisation with e^+e^- interactions at high energy

Klaus Mönig

DESY-Zeuthen

- Effective Polarisations
- Polarimeter measurements and effective polarisations
- Blondel scheme with 2-fermion events
- Polarisation measurement with W-pairs
- Conclusions

Cross section for s-channel vector particle exchange

$$\sigma = \sigma_u \left[1 - \mathcal{P}_{\mathrm{e}^+}\mathcal{P}_{\mathrm{e}^-} + A_{\mathrm{LR}}(\mathcal{P}_{\mathrm{e}^+} - \mathcal{P}_{\mathrm{e}^-})\right]$$

$\mathcal{P}_{\mathrm{e}^+}$ ($\mathcal{P}_{\mathrm{e}^-}$) = longitudinal polarisations of the positrons (electrons)

Relevant combination for A_{LR} measurements:

$$\mathcal{P}_{\mathrm{eff}} = \frac{\mathcal{P}_{\mathrm{e}^+} + \mathcal{P}_{\mathrm{e}^-}}{1 + \mathcal{P}_{\mathrm{e}^+}\mathcal{P}_{\mathrm{e}^-}}$$

Relevant combination for s-channel cross section enhancement/suppression:

$$\mathcal{P}_\sigma = \mathcal{P}_{\mathrm{e}^-}\mathcal{P}_{\mathrm{e}^+}$$

Relevant combination for pure left-handed cross section enhancement/suppression

$$\mathcal{P}_L = \mathcal{P}_{\mathrm{e}^+} - \mathcal{P}_{\mathrm{e}^-} - \mathcal{P}_{\mathrm{e}^+}\mathcal{P}_{\mathrm{e}^-}$$

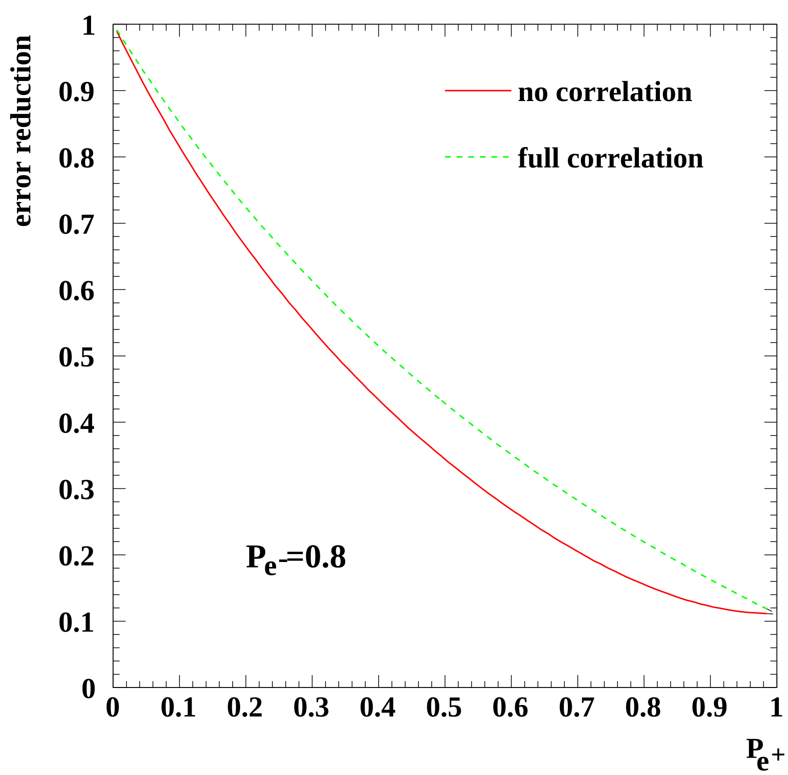
Polarimeter measurements and effective polarisations

- Any LC should have Compton polarimeters
- if positron polarisation is available the error on the effective polarisations is usually smaller than the single polarisation error
- with $\Delta\mathcal{P}/\mathcal{P} = x$ for both polarimeters:
  - if the error is uncorrelated:

$$\frac{\Delta\mathcal{P}_{\mathrm{eff}}}{\mathcal{P}_{\mathrm{eff}}} = x\frac{\sqrt{\left(1-\mathcal{P}_{\mathrm{e^+}}^2\right)^2\mathcal{P}_{\mathrm{e^-}}^2 + \left(1-\mathcal{P}_{\mathrm{e^-}}^2\right)^2\mathcal{P}_{\mathrm{e^+}}^2}}{(\mathcal{P}_{\mathrm{e^+}}+\mathcal{P}_{\mathrm{e^-}})(1+\mathcal{P}_{\mathrm{e^+}}\mathcal{P}_{\mathrm{e^-}})}$$

  - if the error is fully correlated:

$$\frac{\Delta\mathcal{P}_{\mathrm{eff}}}{\mathcal{P}_{\mathrm{eff}}} = x\frac{1-\mathcal{P}_{\mathrm{e^+}}\mathcal{P}_{\mathrm{e^-}}}{1+\mathcal{P}_{\mathrm{e^+}}\mathcal{P}_{\mathrm{e^-}}}$$



Assume only s-channel vector exchange

Four independent measurements:
(4 combinations with positive/negative electron/ positron polarisation)

$$\begin{aligned}
\sigma_{++} &= \sigma_u\left[1 - \mathcal{P}_{\mathrm{e}^+}\mathcal{P}_{\mathrm{e}^-} + A_{\mathrm{LR}}(\ \ \mathcal{P}_{\mathrm{e}^+} - \mathcal{P}_{\mathrm{e}^-})\right]\\
\sigma_{-+} &= \sigma_u\left[1 + \mathcal{P}_{\mathrm{e}^+}\mathcal{P}_{\mathrm{e}^-} + A_{\mathrm{LR}}(-\mathcal{P}_{\mathrm{e}^+} - \mathcal{P}_{\mathrm{e}^-})\right]\\
\sigma_{+-} &= \sigma_u\left[1 + \mathcal{P}_{\mathrm{e}^+}\mathcal{P}_{\mathrm{e}^-} + A_{\mathrm{LR}}(\ \ \mathcal{P}_{\mathrm{e}^+} + \mathcal{P}_{\mathrm{e}^-})\right]\\
\sigma_{--} &= \sigma_u\left[1 - \mathcal{P}_{\mathrm{e}^+}\mathcal{P}_{\mathrm{e}^-} + A_{\mathrm{LR}}(-\mathcal{P}_{\mathrm{e}^+} + \mathcal{P}_{\mathrm{e}^-})\right]
\end{aligned}$$

$\Longrightarrow$ Can measure $\mathcal{P}_{\mathrm{e}^+}$, $\mathcal{P}_{\mathrm{e}^-}$ simultaneously with A_{LR} if $A_{\mathrm{LR}} \neq 0$

$$\mathcal{P}_{e^\pm} = \sqrt{\frac{(\sigma_{+-}+\sigma_{-+}-\sigma_{++}-\sigma_{--})(\mp\sigma_{+-}\pm\sigma_{-+}-\sigma_{++}+\sigma_{--})}{(\sigma_{+-}+\sigma_{-+}+\sigma_{++}+\sigma_{--})(\mp\sigma_{+-}\pm\sigma_{-+}+\sigma_{++}-\sigma_{--})}}$$

Only difference between $|\mathcal{P}^{+}_{\mathrm{e}^\pm}|$ and $|\mathcal{P}^{-}_{\mathrm{e}^\pm}|$ needs to be known from polarimetry

Available event samples

- $\mathrm{f\bar{f}}$ events at the highest energy (HE)
- radiative return events $\mathrm{e^+e^-} \rightarrow Z\gamma \rightarrow \mathrm{f\bar{f}}\gamma$ (RR)

$\sqrt{s}$	σ_{RR}	$A_{\mathrm{LR}}(RR)$	σ_{HE}	$A_{\mathrm{LR}}(HE)$
340 GeV	17 pb	0.19	5 pb	0.50
500 GeV	7 pb	0.19	2 pb	0.50

HE events

- easy and background free to select
- large A_{LR} reduces error on $\mathcal{P}$
- however physics assumption on s-channel vector exchange
  (not valid for RPV $\tilde{\nu}$ or extra dimensions)

RR events

- large cross section
- well known physics (LEP,SLC)
- however large ($\sim$ 30%) Zee background at high energies when photon not reconstructed
- Way out: photon reconstruction

➠ only 9% efficiency with cut at $\theta_\gamma > 7^\circ$

Radiative corrections

- for HE sample depolarising effects of ISR are small
- for RR sample they are about 1% if photon is not reconstructed
- if photon is reconstructed, they are negligible

Assume:

- $\mathcal{P}_{e^-} = 0.80,\ \mathcal{P}_{e^+} = 0.60$
- $\sqrt{s} = 340\,\mathrm{GeV}$ (results scale with $\sqrt{\sigma}$)
- $\mathcal{L} = 500\,\mathrm{fb}^{-1}$
- Luminosity ratio
  $+-/-+/++/-- = 1/1/1/1$

Radiative return:

$$\frac{\delta\mathcal{P}_{e^-}}{\mathcal{P}_{e^-}} = 0.0051 \quad \frac{\delta\mathcal{P}_{e^+}}{\mathcal{P}_{e^+}} = 0.0053 \quad corr. = -0.91$$

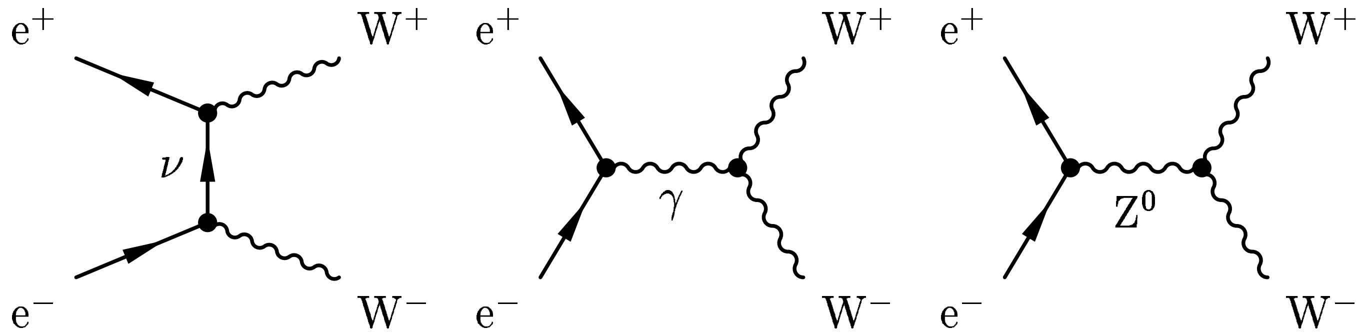
High energy:

$$\frac{\delta\mathcal{P}_{e^-}}{\mathcal{P}_{e^-}} = 0.0010 \quad \frac{\delta\mathcal{P}_{e^+}}{\mathcal{P}_{e^+}} = 0.0012 \quad corr. = -0.49$$

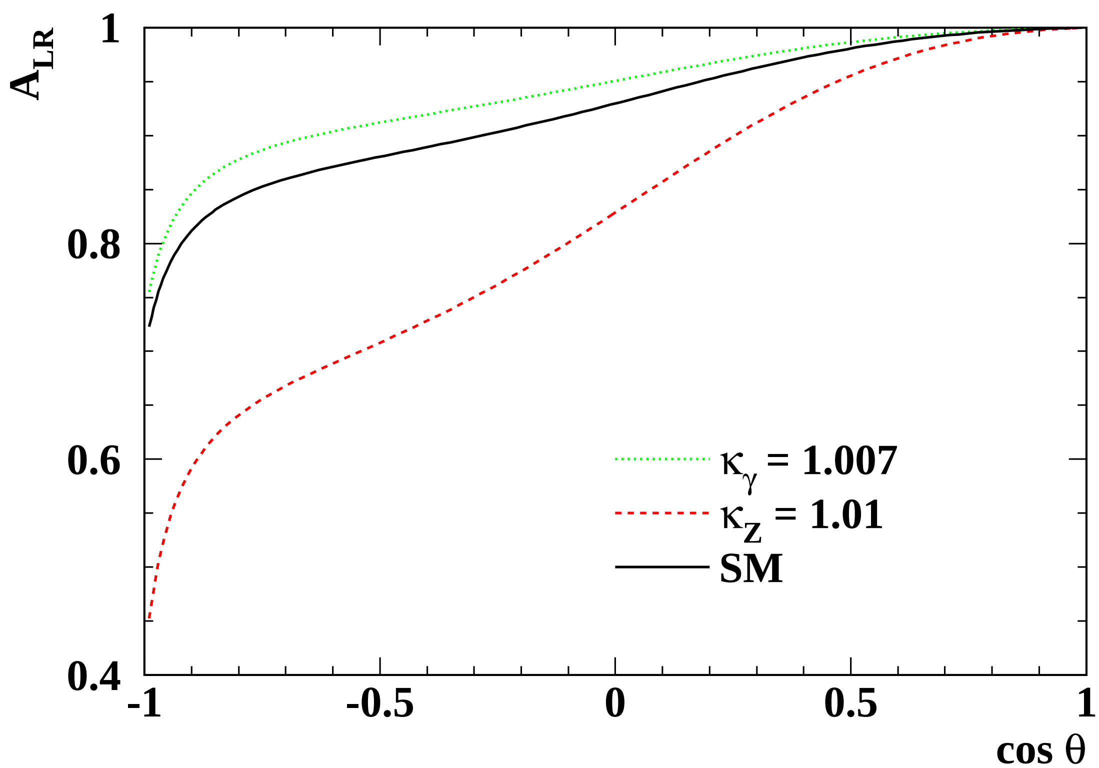
- Luminosity ratio
  $+-/-+/++/-- = 9/9/1/1$

Errors ~factor two larger

Polarisation measurement with W-pairs



- Cross section $\sigma = 12 - 7\,\mathrm{pb}$ at $\sqrt{s} = 350 - 500\,\mathrm{GeV}$
- complicated mixture of ν t-channel and Z, γ s-channel exchange
- large left-right asymmetry, depending on production angle and assumed couplings



- fit simultaneously polarisations and anomalous couplings

Up to now only analysis with analytic Born level formulae and approximate acceptance cuts

(The analysis has however been checked to reproduce the anomalous couplings)

Results:

$\mathcal{L}_{\pm\pm}/\mathcal{L} = 0.5$

$$\frac{\delta\mathcal{P}_{\mathrm{e}^-}}{\mathcal{P}_{\mathrm{e}^-}} = 0.0007 \quad \frac{\delta\mathcal{P}_{\mathrm{e}^+}}{\mathcal{P}_{\mathrm{e}^+}} = 0.0011 \quad corr. = 0$$

$\mathcal{L}_{\pm\pm}/\mathcal{L} = 0.1$

$$\frac{\delta\mathcal{P}_{\mathrm{e}^-}}{\mathcal{P}_{\mathrm{e}^-}} = 0.0011 \quad \frac{\delta\mathcal{P}_{\mathrm{e}^+}}{\mathcal{P}_{\mathrm{e}^+}} = 0.0021 \quad corr. = -0.52$$

Results for the effective polarisations:

	value	Rel. error [%]							
		$\mathcal{L}_{\pm}\pm/\mathcal{L} = 0.5$			$\mathcal{L}_{\pm\pm}/\mathcal{L} = 0.1$			Polarimeter	
		HE	rr	WW	HE	rr	WW	$\rho=0$	$\rho=0.5$
$\mathcal{P}_{\mathrm{eff}}$	0.95	0.02	0.08	0.02	0.05	0.17	0.02	0.13	0.16
$\mathcal{P}_{\sigma}$	0.48	0.11	0.22	0.13	0.18	0.42	0.18	0.71	0.87
$\mathcal{P}_{L}$	0.92	0.03	0.12	0.03	0.06	0.25	0.03	0.19	0.21

$$\mathcal{P}_{\mathrm{eff}} = \frac{\mathcal{P}_{\mathrm{e}^+} + \mathcal{P}_{\mathrm{e}^-}}{1 + \mathcal{P}_{\mathrm{e}^+}\mathcal{P}_{\mathrm{e}^-}}$$

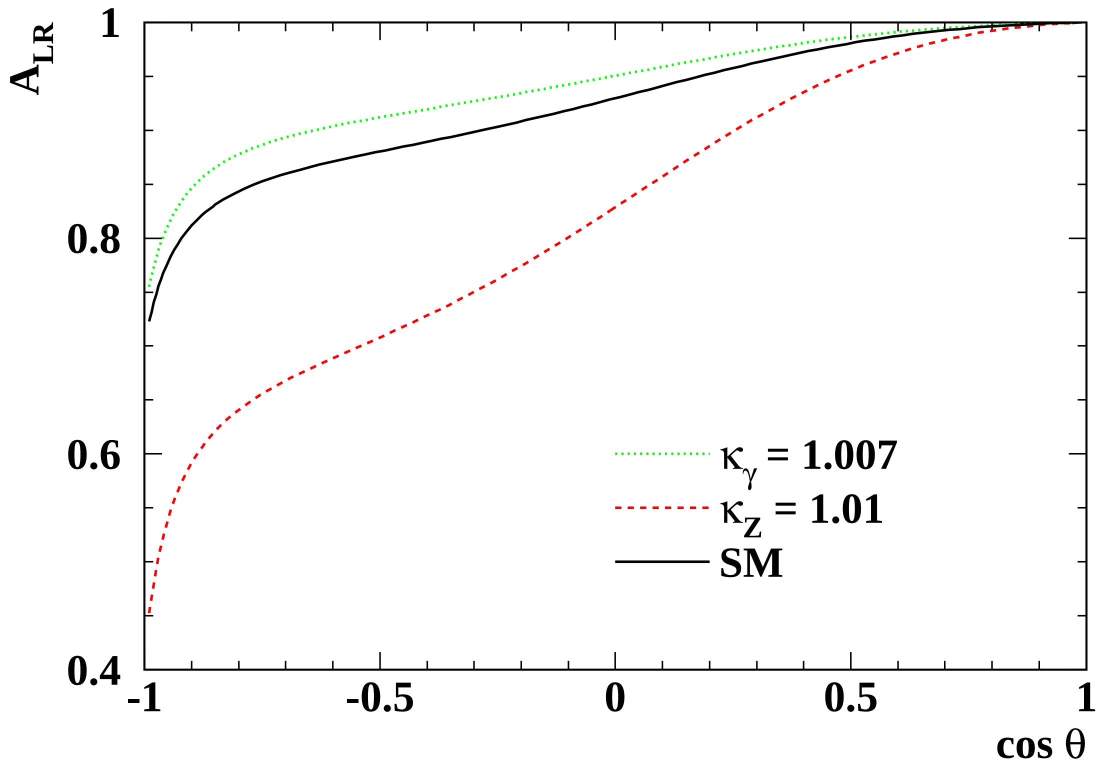
$$\mathcal{P}_{\sigma} = \mathcal{P}_{\mathrm{e}^-}\mathcal{P}_{\mathrm{e}^+}$$

$$\mathcal{P}_{L} = \mathcal{P}_{\mathrm{e}^+} - \mathcal{P}_{\mathrm{e}^-} - \mathcal{P}_{\mathrm{e}^+}\mathcal{P}_{\mathrm{e}^-}$$

Data methods have a high potential if positron polarisation available

- forward peak dominated by ν-exchange

➠ $A_{\mathrm{LR}} = 1$ independent of anomalous couplings



- can fit for $\mathcal{P}_{\mathrm{e}^-}$ and couplings simultaneously also if only electron polarisation available
- result with $\mathcal{L} = 500\,\mathrm{fb}^{-1}$ at $\sqrt{s} = 340\,\mathrm{GeV}$:

$$\Delta\mathcal{P}_{\mathrm{e}^-}/\mathcal{P}_{\mathrm{e}^-} = 0.1\%$$

correlations with the couplings negligible

A similar precision should be possible with single W production, but no studies yet

Conclusions

- If polarised electrons and positrons are available the polarisation can be measured in a model independent way from the data themselves.

- The errors are in the below per mille region for $500\,\mathrm{fb}^{-1}$

- The exact requirements have be studied by the different analyses separately

- At high energy W-production might offer the possibility to measure beam polarisation with polarised electrons only